

# **Pedestrian Ventilation System: A Novel Approach to Mitigate Urban Heat Islands**

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Fariborz Haghighat**

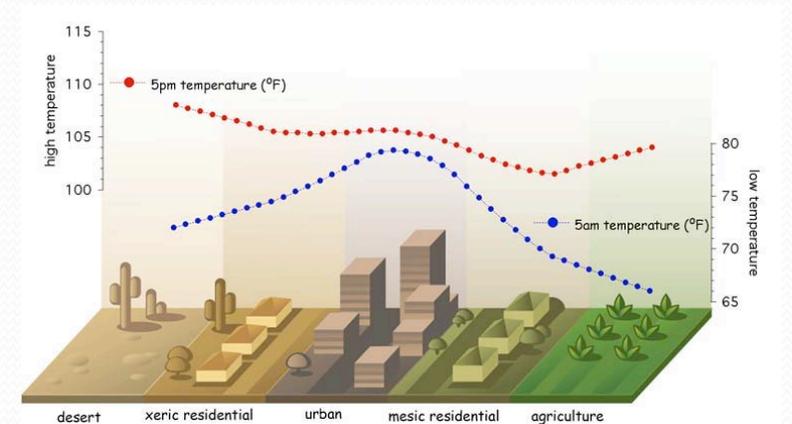
**Concordia University, Montreal, Canada**

# Outline

- Research Motivation
- Pedestrian Ventilation System (PVS)
  - PVS Strategies
- Feasibility of the PVS
  - Case Studies
  - CFD Simulation
  - Results
- Conclusion

## Research Motivation

Urban heat islands decrease pedestrian comfort.  
(Temperature, Relative Humidity, Air Velocity,  
Radiation, and Pollution)



Moreover, most of the high-rise street canyons have:

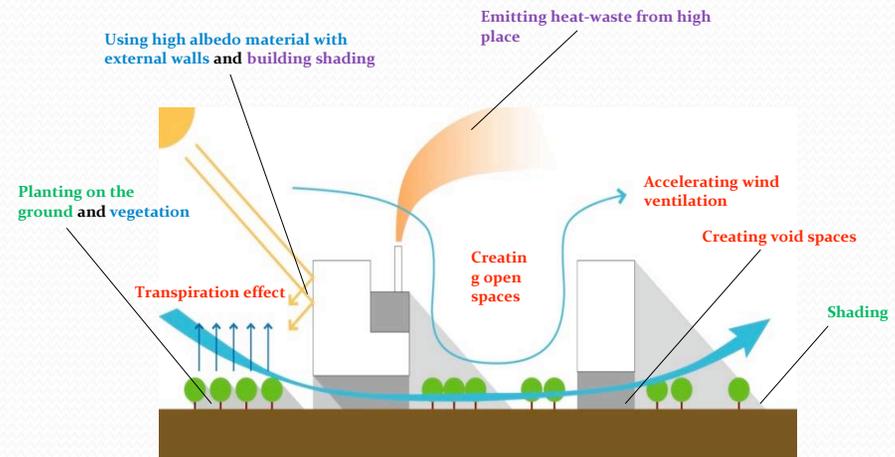
- High release of anthropogenic energy
- Weak air movement
- Heavy vehicular pollution emission



# UHI Mitigation Strategies

## strategies

1. Urban ventilation
2. Shading
3. Urban materials alteration
4. Anthropogenic heat release reduction



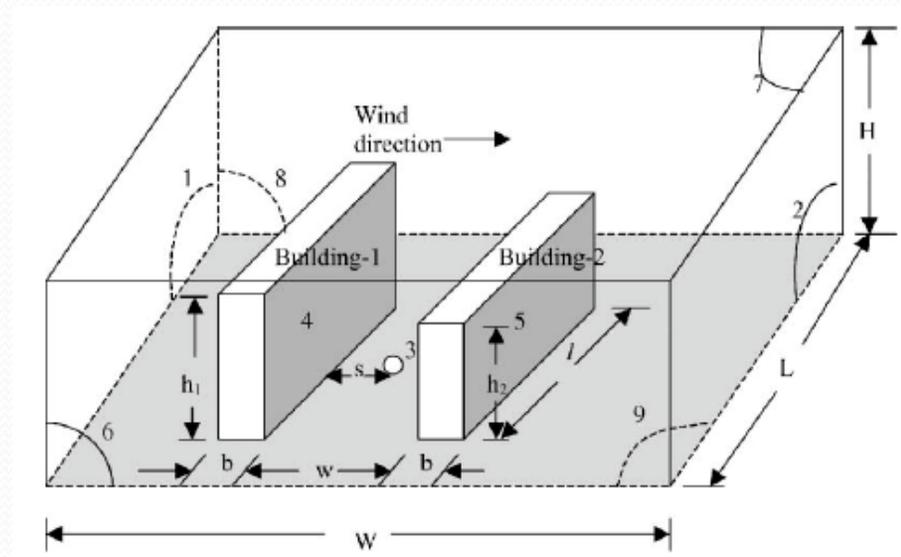
## Limitations of Current Strategies for Pedestrian Comfort:

- Not applicable for **constructed canyons**
- Different **spatial and temporal** performance of countermeasures

**Current strategies are Passive techniques**

## Different Spatial and Temporal Performance of Countermeasures

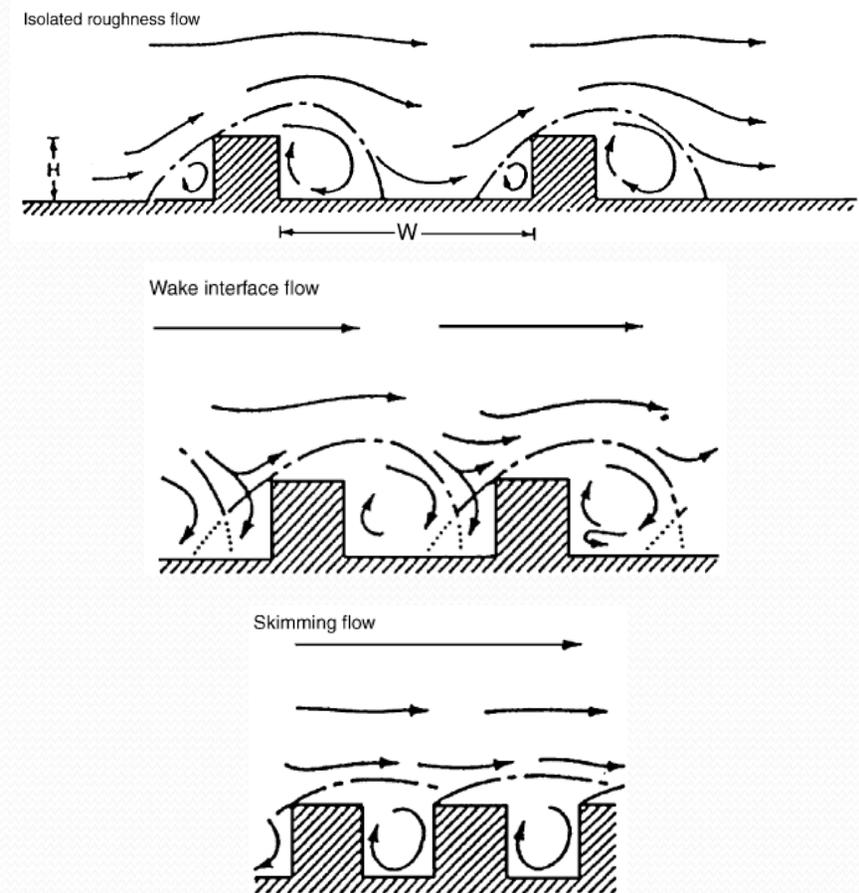
- Important parameters of street canyon:
  - Aspect ratio
  - Roof shape
  - Type of street canyon
    - Symmetric
    - Step-up
    - Step-down
  - Canopy length to height
    - Short ( $L/H=3$ )
    - Medium ( $L/H=5$ )
    - Long canyons ( $L/H=7$ )
  - Stratification
    - Ground heating
    - Wall heating
  - Prevailing wind velocity and direction



## Air Movement within Street Canopies - Aspect Ratio

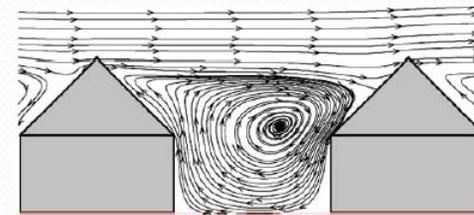
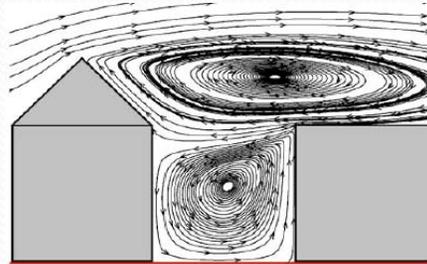
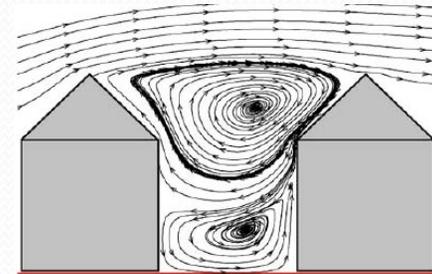
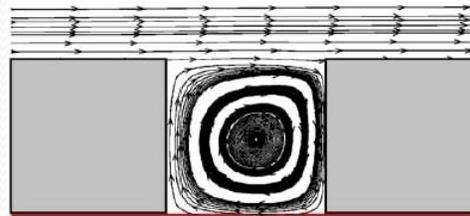
Oke (1988) summarized the flow regime within street canopy based on aspect ratio:

- Isolated roughness flow
- Wake interface flow
- Skimming flow

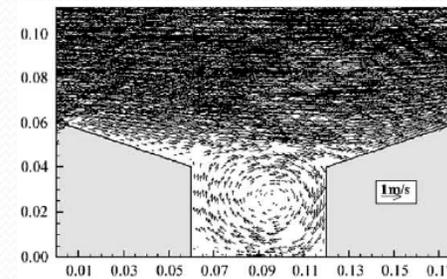
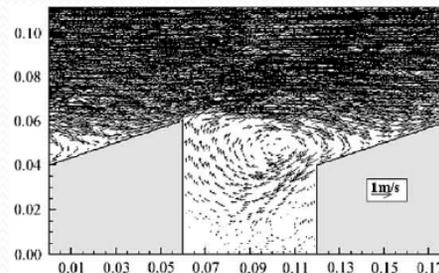
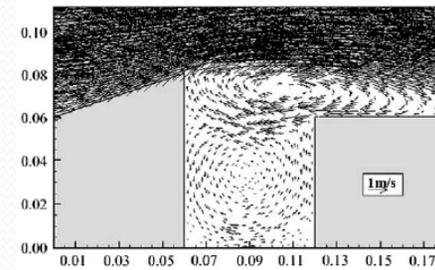
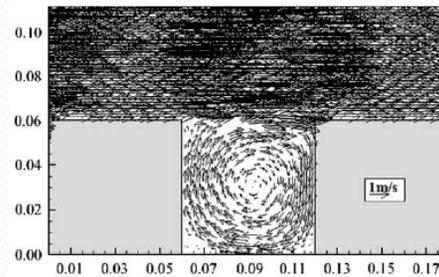


# Air Movement within Street Canopies - Roof Shape

- Xie (2005)



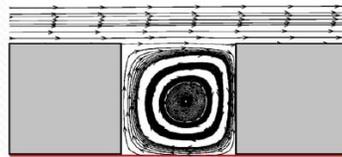
- Huang (2009)



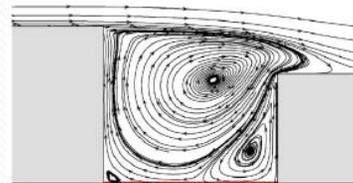
# Air Movement within Street Canopies - Canopy Type

- Xie (2006)

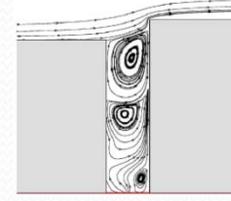
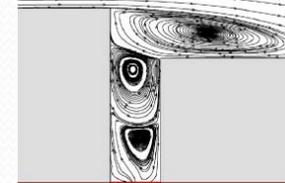
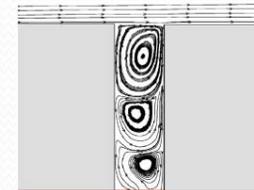
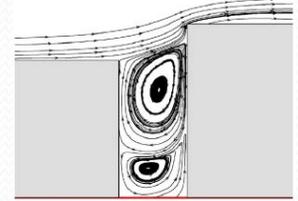
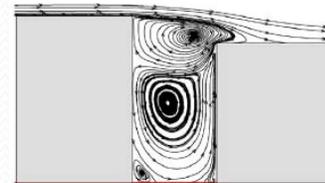
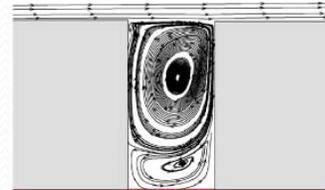
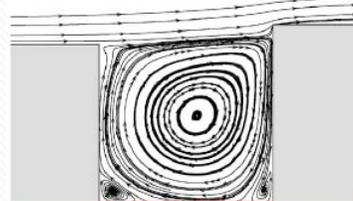
- Symmetric



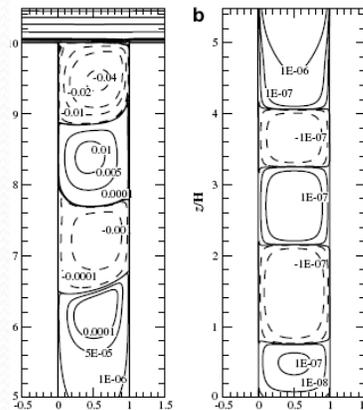
- Step-up



- Step-down



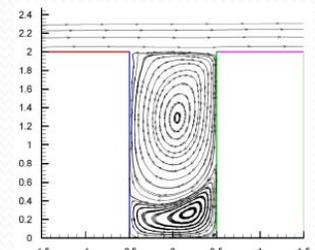
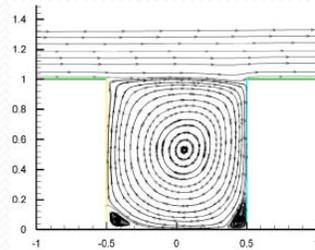
- Lie (2009)  
(Aspect ratio=10)



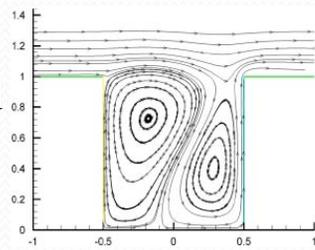
# Air Movement within Street Canopies - Stratification

- Xie (2007)

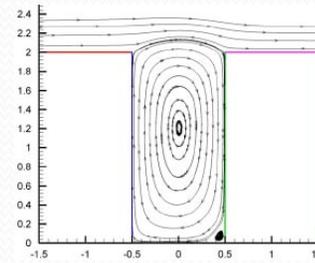
- Isothermal



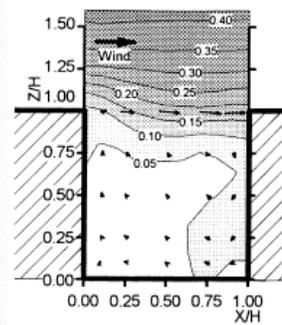
- Heated ground



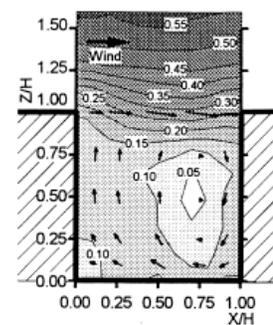
Heated wall



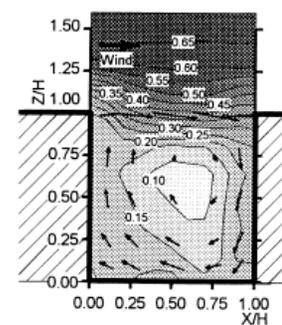
- Uehara (2000)



a)  $R_b = 0.79$



b)  $R_b = 0$



c)  $R_b = -0.21$

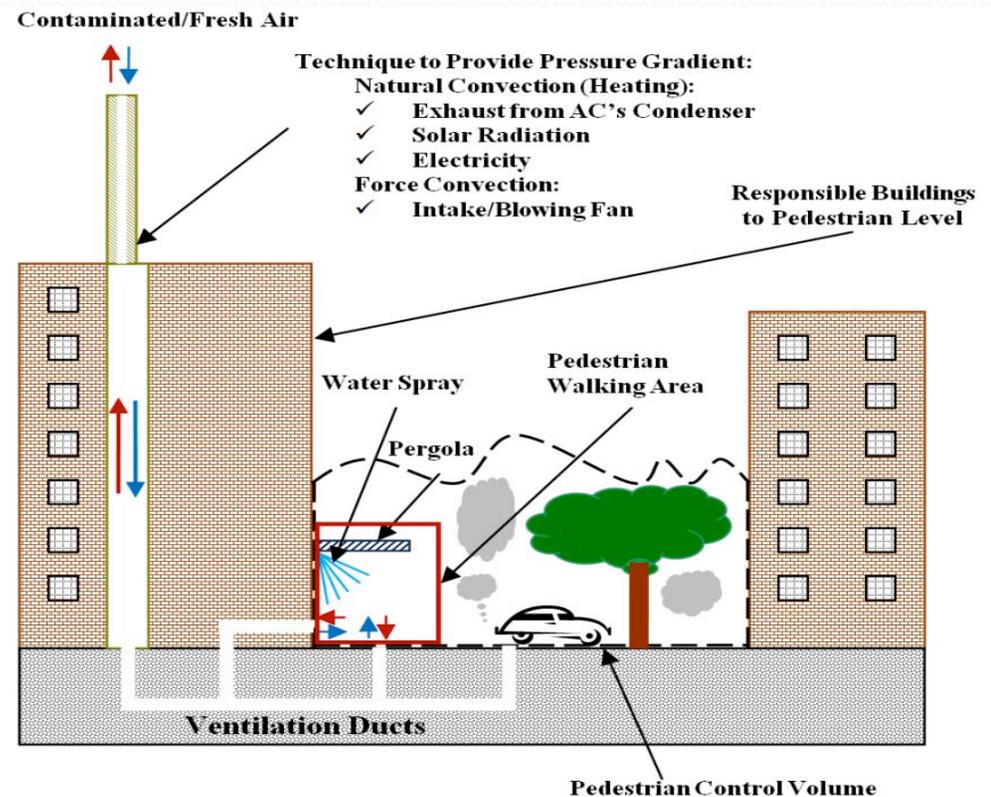
# Design and Propose a Novel Pedestrian Ventilation System (PVS)

## Pedestrian level comfort based on:

- Temperature
- Humidity
- Air velocity
- Radiation
- Pollution concentration

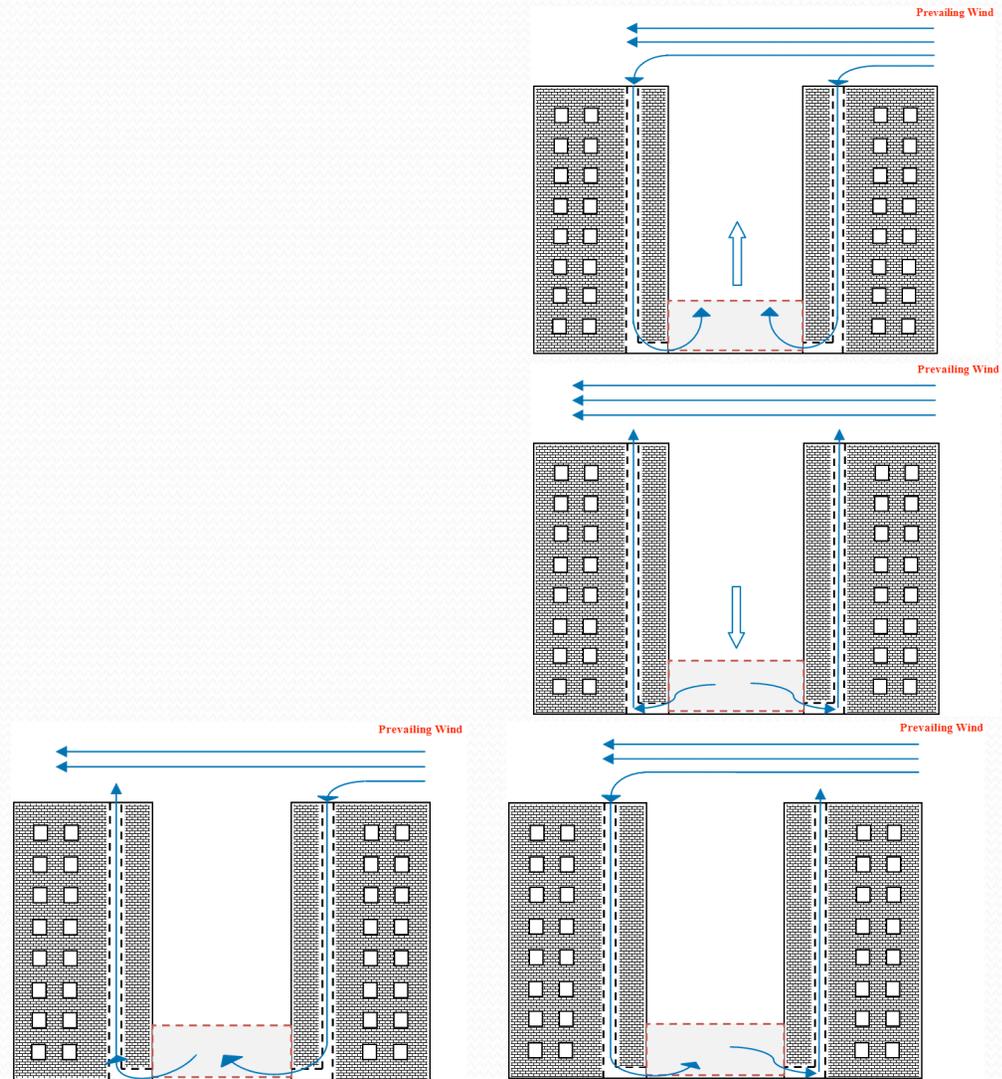
## On-site control to obtain a consistent range of pedestrian comfort:

- Ventilation duct (filter)
- Water spray
- Pergola



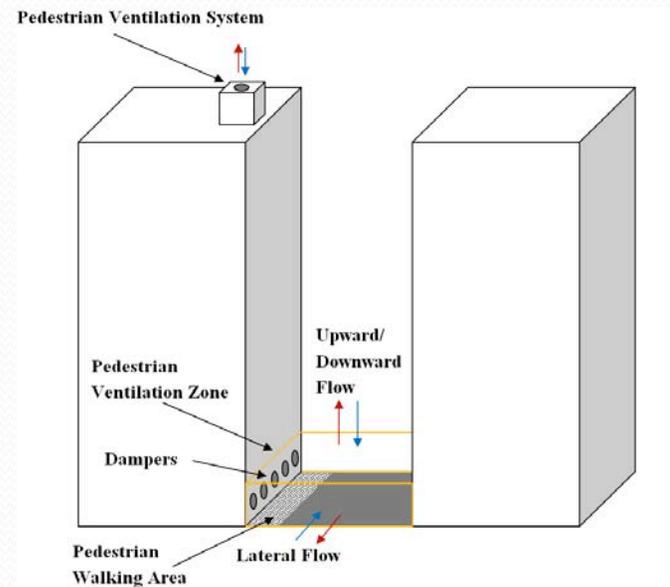
# The PVS Alternatives

- Supplying air (A)
- Exhausting air (B)
- Washing flow (C) and (D)



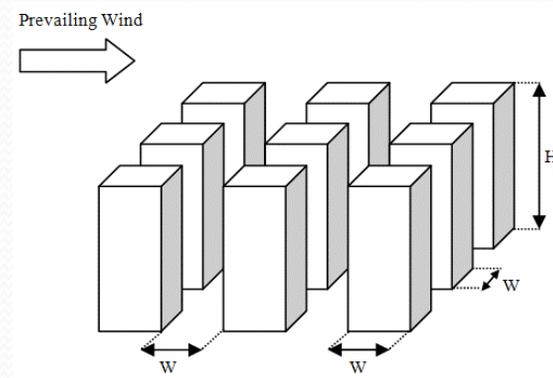
## Feasibility of the PVS

- Entering or leaving air from the lateral and top faces of the pedestrian ventilation zone
- Pollution concentration
- Air velocity
- Air temperature



## Case Study:

- An array of buildings with simple geometry (size of Concordia University)
- Aspect ratio = 2
- 3 dampers on each sidewalk
- PVZ = 1200 cubic meter



## Case Study

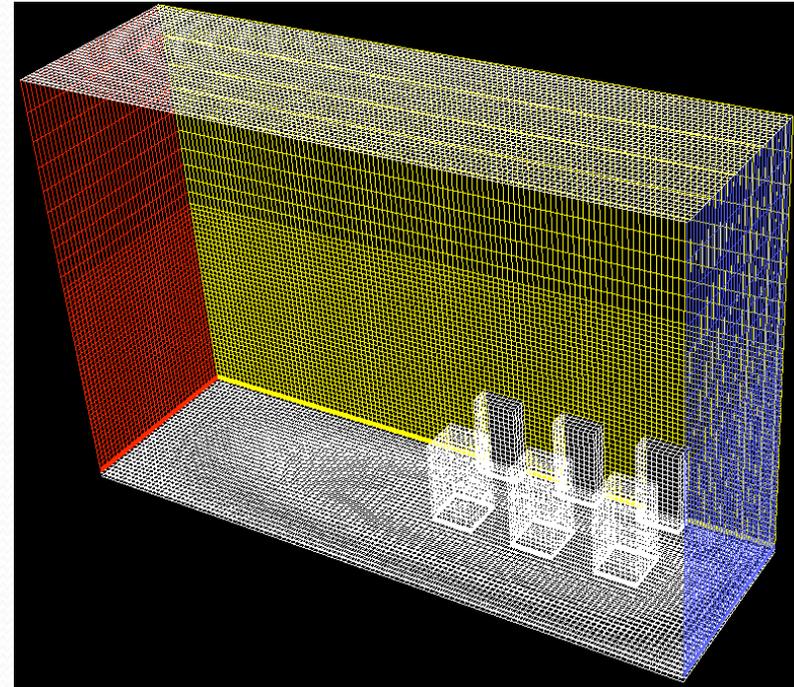
- Bulk-Richardson number as stability criterion (Uehara 2000)

	Stability Condition	Bulk-Richardson Number	$T_a$ = Wind Temperature (°K)	$T_f$ = Ground Temperature (°K)
Case I	Stable	1.52	78	21
Case II	Unstable	-1.24	20	79

- Stable condition:  
Removing trapped pollutant from the PVZ which mostly occurs in nocturnal non-cloudy calm weather
- Unstable situation:  
Taking the advantage of colder mean flow over the canopy

## Model Description

- 3D CFD
- $k - \dot{a}$  Model
- Half-Million meshes
- Fine + coarse Meshes
- Half-domain calculation

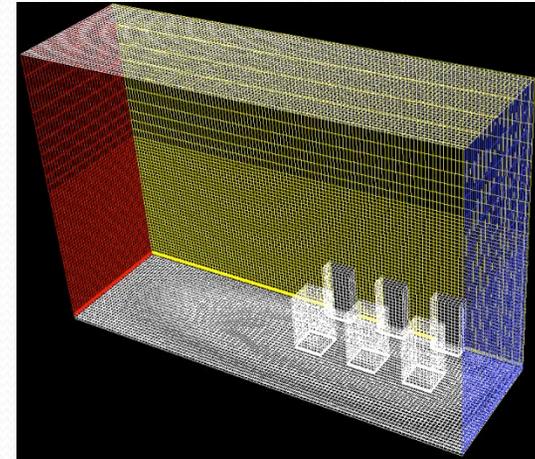
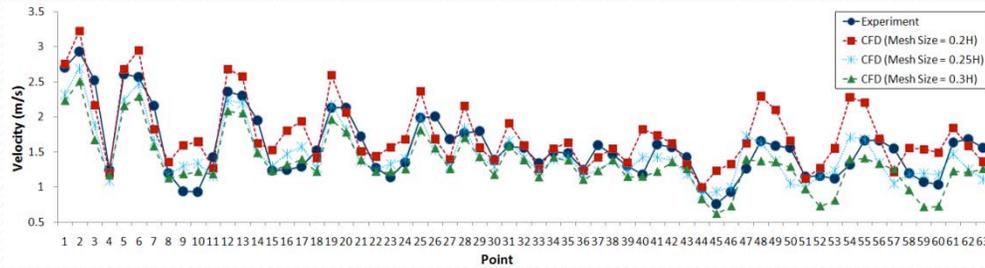


### Boundary Condition:

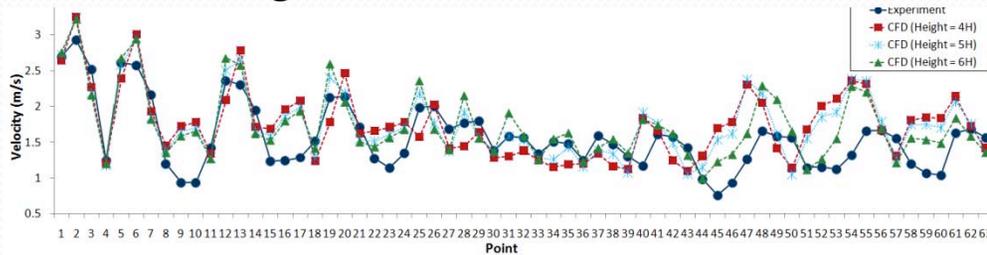
<b>Inflow boundary</b>	Logarithmic flow Tominaga et al. (2005)
<b>Outflow boundary</b>	Zero gradient assumption
<b>Ground boundary</b>	Logarithmic law with roughness length (0.024m)
<b>Upper and side surface of domain</b>	Free slip wall condition
<b>Building surface boundary</b>	Logarithmic law for smooth wall
<b>Turbulent scheme</b>	Standard $k - \dot{a}$
<b>Advection scheme</b>	Second order Upwind for velocity and pressure
<b>Computational domain</b>	$180m(x) \times 280m(y) \times 120m(z)$

# Mesh and domain size optimization

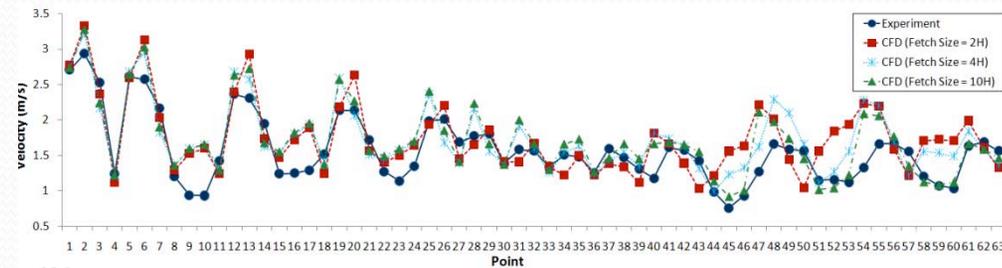
- Mesh size



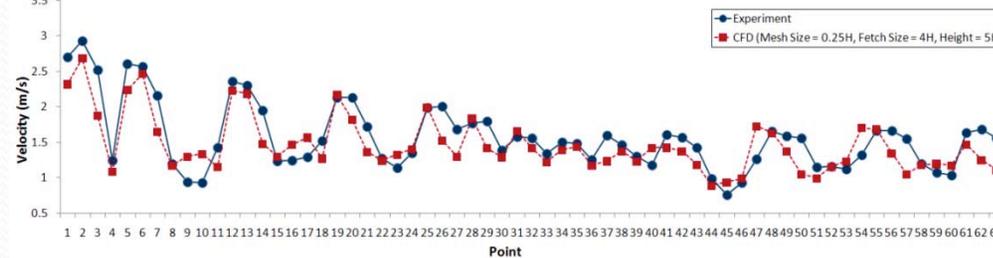
- Domain height size



- Domain fetch size

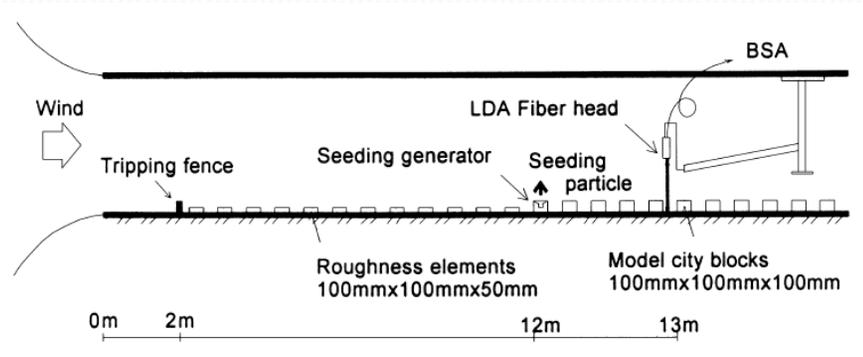


- Final dimensions

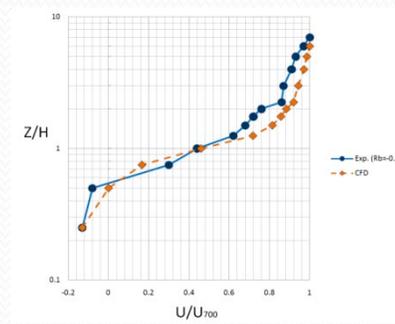
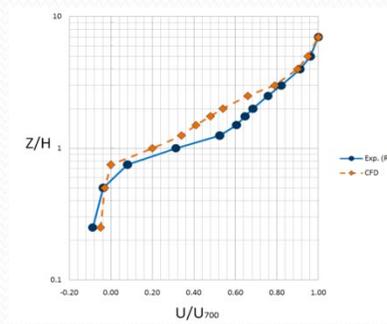
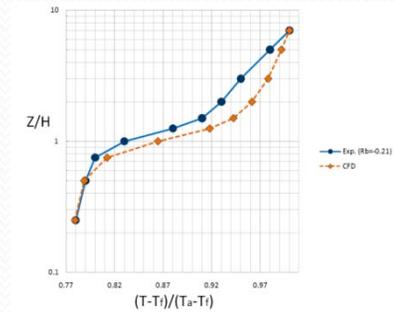
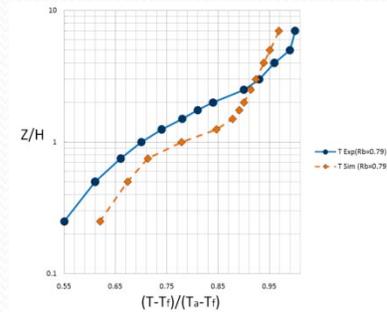
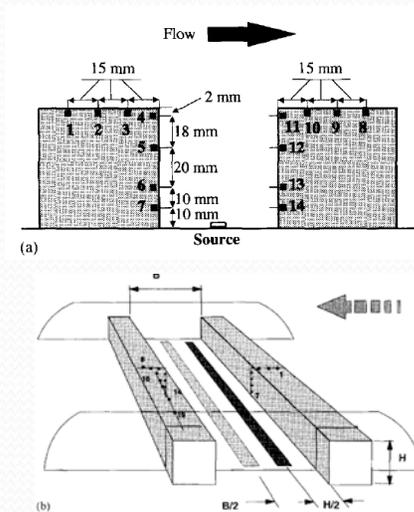


# Verification of Simulation

- Velocity and temperature verification (Uehara et al. 2000)

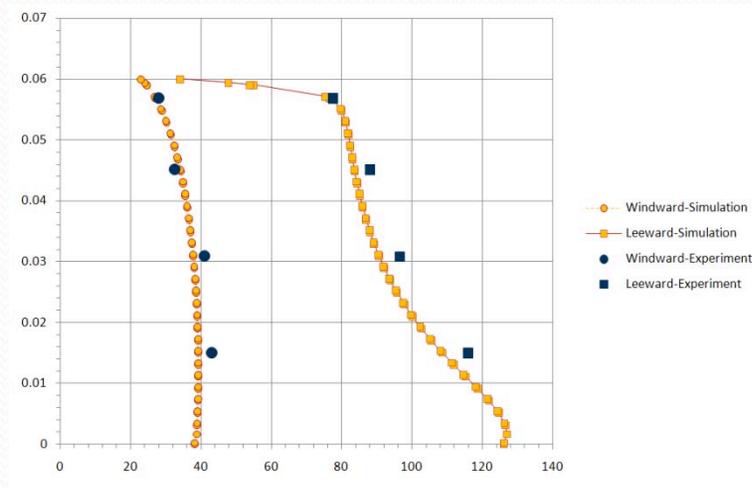


- Pollution concentration verification (Meroney 1996)



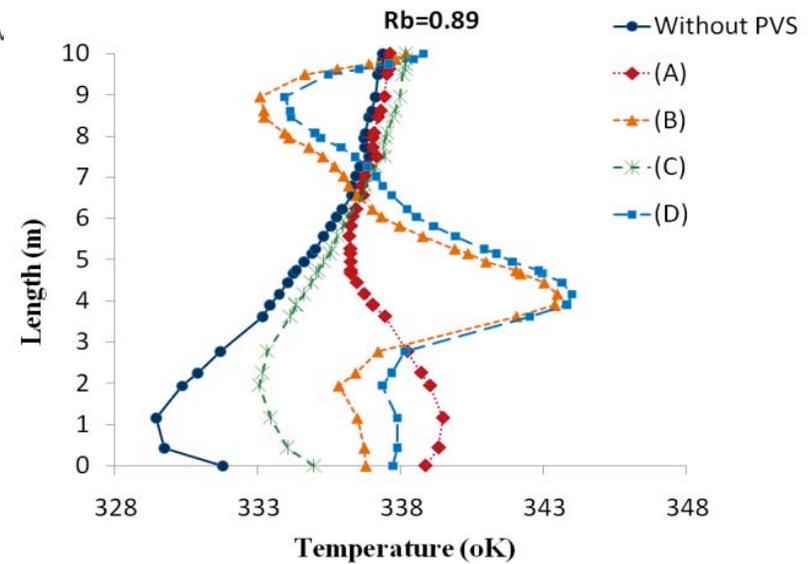
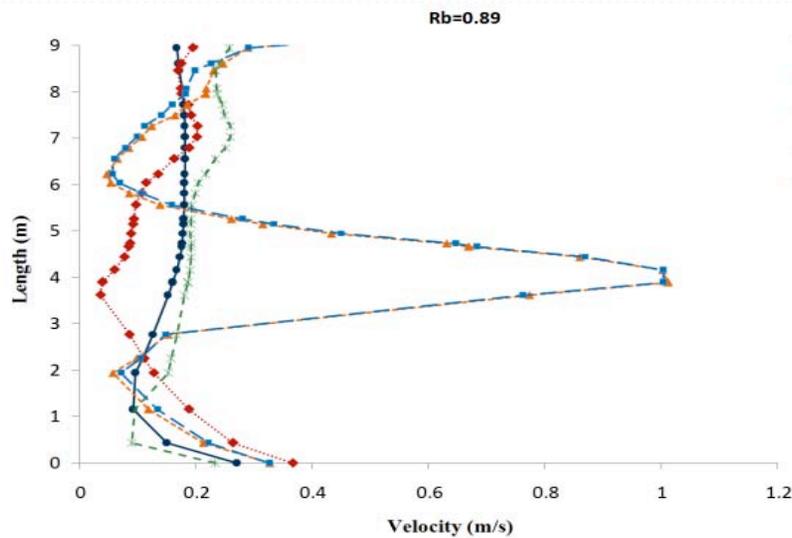
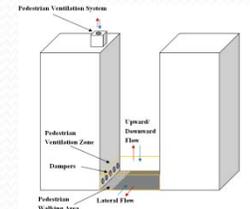
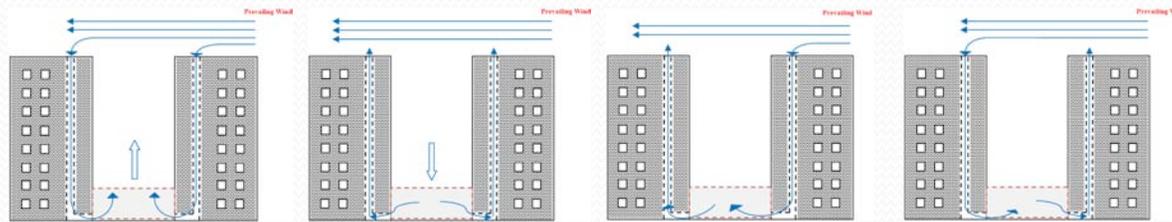
Stable

Unstable



# Result

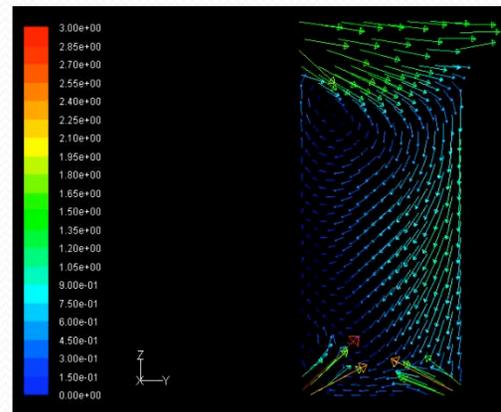
Strategy	Without PVS	A	B	C	D
<b>Stable Condition (Bulk-Richardson = 0.89)</b>					
Air flow rate from lateral-surfaces of the PVZ (m <sup>3</sup> /s)	-7.49	0.35	-26.99	-18.55	-18.84
Air flow rate from top-surface of the PVZ (m <sup>3</sup> /s)	7.49	12.34	3.08	12.45	13.96
The PVZ air removal per minute	0.05	0.63	1.2	0.31	0.24
<b>Unstable Condition (Bulk-Richardson = -0.18)</b>					
Air flow rate from lateral-surfaces of the PVZ (m <sup>3</sup> /s)	-35.49	-17.45	-51.27	-24.33	-42.06
Air flow rate from top-surface of the PVZ (m <sup>3</sup> /s)	35.49	30.68	33.91	20.82	40.09
The PVZ air removal per minute	0.10	0.66	0.87	0.18	0.10



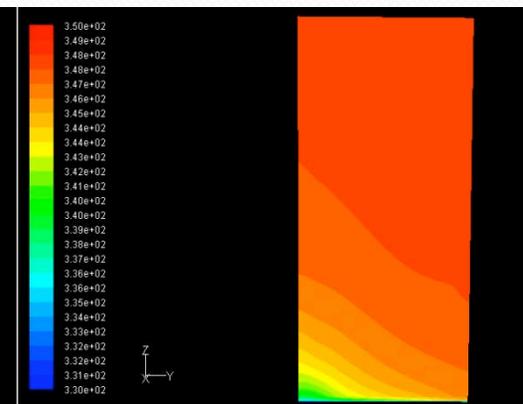
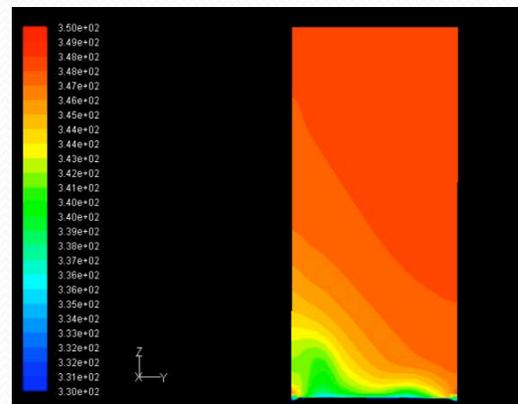
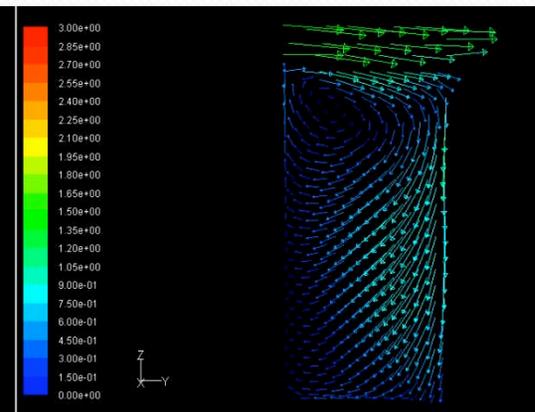
## Results-Unstable Condition ( $Rb=1.52$ )

- Alternative (A), supplying mechanism, prepare better air exchange for pedestrians
- Each 80 seconds the pedestrian ventilation volume can be removed once
- Wind velocity increases from 0.2 m/s, light air situation to 0.9 m/s or light breeze range

Alternative (A)



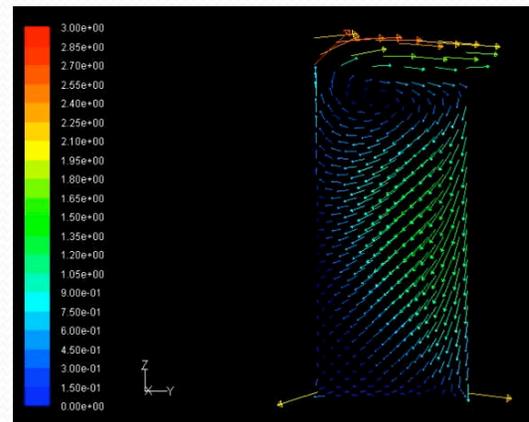
Before PVS



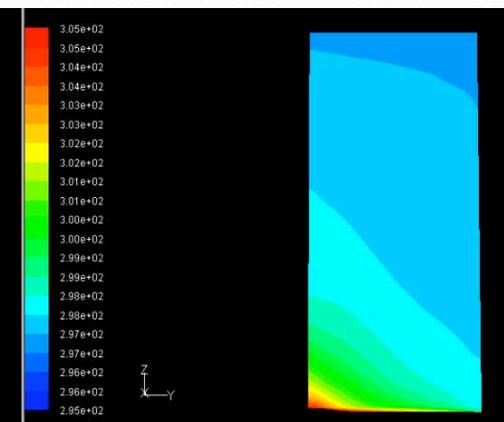
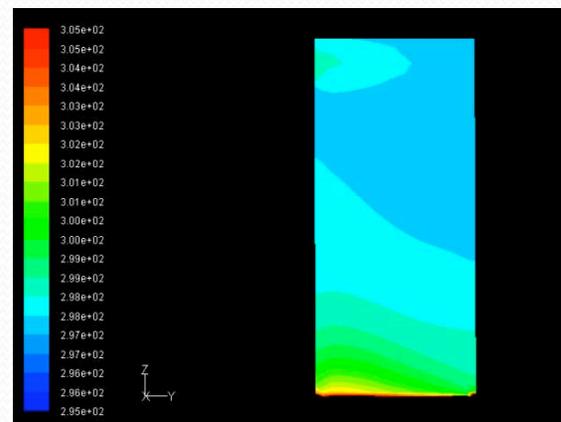
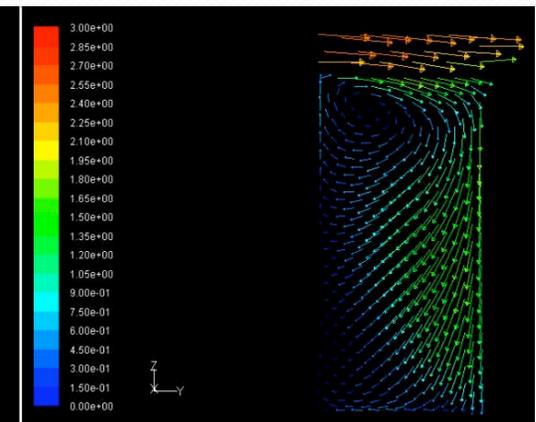
## Results-Stable Condition ( $Rb = -1.24$ )

- Alternative (B), exhausting mechanism, prepare acceptable air exchange for pedestrians (0.9)
- Appropriate to guide colder roof-level air through the building canopy
- Wind velocity demonstrates same range in all cases

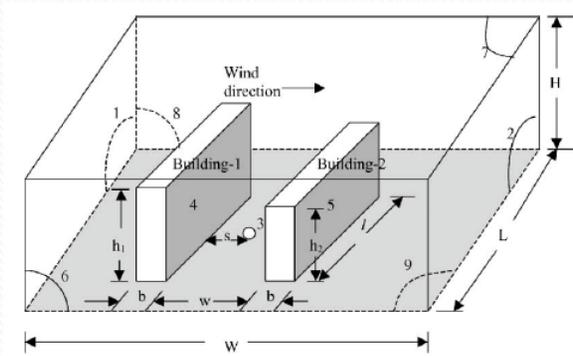
Alternative (B)



Before PVS

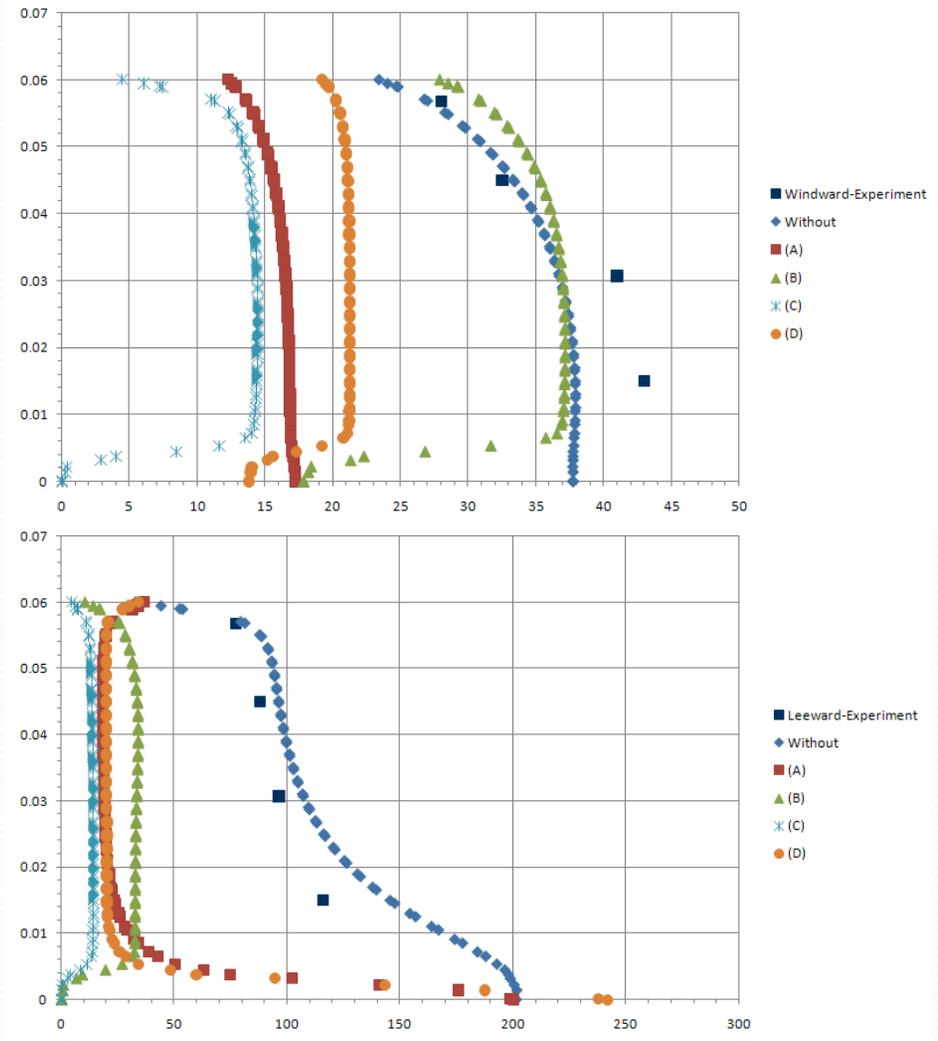


# Results- Pollution Concentration



Windward wall

Leeward wall



# Conclusion

- Current mitigation strategies are passive approaches, and their performance changes spatially and temporally inside a city
- **PVS** has been proposed as a flexible technique to enhance pedestrian air quality comfort following by four main alternatives to control air quality of the pedestrian zone
- The preliminary Study shows the capability of the PVS to apply different alternatives to achieve better air quality under different weather stability

**Thank you for your attention!**